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Evaluation and calibration of some potential evapotranspiration estimating methods

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ABSTRACT

Potential evapotranspiration (PET) data are being used for estimation of crop water requirement and mapping the irrigation need. Modified Penman method, requires extensive data and use of complex formulae and thus there is a need to find a simple relation requiring limited data. The PET values for a 6-year period as estimated by four empirical relations namely Thornthwaite, Hargreaves, Turc and Baier were compared with that estimated by Penman method. Thornthwaite, Turc relations have over-estimated and relation of Baier under-estimated. Of the four, Hargreaves estimates were close to the Penman's. On an average, Hargreaves relation resulted in 21 per cent error. Data when separated season-wise have indicated that relations differed in their accuracy during the three seasons. Calibration coefficients evolved for all the four relations on annual as well as on season basis reduced the errors in PET estimation.

Key words : Potential evapotranspiration, Methods, Calibration

Potential evapotranspiration (PET) data is used to estimate regional evapotranspiration (ET), which is the amount of water lost from an extensive short green vegetation that completely covered the ground under conditions of unlimited and unrestricted water supply. The data on PET is also useful to estimate potential crop production and crop water requirement through use of crop-coefficient value (K_c), a ratio of ET and PET.

The data on measured PET under ideal conditions as defined is difficult to obtain for many parts of India. Several empirical formulae have been proposed for the estimation of PET directly from meteorological data. Of all the methods, modified Penman method (Doorenbos and Pruitt, 1977), has recieved wide acceptability. It was found to yield reasonableble estimates of PET for a number of Indian stations (Rao *et al.*, 1971) and the estimates were closer to the experimentally determined values (Olaniram, 1981 and Rao *et al.*, 1983). A simple empirical formula with computational convenience but with sufficient accuracy need to be identified taking into consideration limited meteorological data available at many of the Indian stations. Kumar *et al.*, (1987) found a seasonal influence on PET estimates for many Indian stations. In this present study an attempt has therefore been made to identify suitable empirical relations among the four viz., Thornthwaite (1948) later modified by Thornthwaite and Mather (1955), Hargreaves *et al.* (1985) and Baier *et al.* (1978) that require temperature as the only measured input as well as Turc (1961) method requiring additionally hours of bright sunshine. An attempt has also been made to study the influence of season on such relations.

MATERIALS AND METHODS

The data required for the comparison of different formulae were collected from meteorological observatory located on the Agricultural Farm, Bapatla (15° 54' N, 82° 30' E and 5m AMSL) for the period 1991 -1996. On some days all the data for computation of PET by Penman method were not available and hence those days were not considered, thus, making a total data set of 1757 days. The daily PET was estimated using different formulae as follows:

Modified Penman method

$$PET = C\,[W.\,R_n + (1-W).\,f(u).(e_a - e_d)] \quad .....(Eq.1)$$

where,

PET = reference crop evapotranspiration in mm day^{-1}

W = temperature related weighing factor

R_n = net radiation in equivalent evaporation in mm day^{-1}

f(u) = wind related function

$(e_a - e_d)$ = difference between the saturation vapour pressure at mean air temperature and the mean actual vapour pressure of the air both in mb

C = adjustment factor to compensate for the effect of day and night weather conditions. All the above parameters were deduced as per the procedure outlined by Doorenbos and Pruitt (1977).

Thornthwaite method

$$PET = 1.6\ l\ (10\,t / I)^a \quad ...(Eq.2)$$

where,

PET = adjusted potential evapotranspiration in cm (12 hrs. day time)

t = mean temperature in °C

I = annual heat index = $\Sigma\,(t_i/5)^{1.514}$

t_i = temperature in °C of the i th month

a = an empirical exponent = $6.75 \times 10^{-7} I^3 - 7.71 \times 10^{-5} I^2 + 1.792 \times 10^{-2} I + 0.49239$

l = day length factor.

The values of I and a used for Bapatla and calculated from long term meteorological data were I = 162.812 and a = 4.272.

Hargreaves method

$$PET = 0.0023\,R_A\ T_D^{0.5}\,(T+17.8) \quad ...(Eq.3)$$

where,

R_A = extra-terrestrial radiation in mm day^{-1}

T_D = difference between maximum and minimum temperature in °C

T = mean temperature in °C.

The value of R_A on any given day was deduced from the Table 2 of Doorenbos and Pruitt (1977).

Turc method

$$PET = 0.40\,T\,(R_s + 50) / (T + 15) \quad ... (Eq.4)$$

where,

T = mean air temperature in °C

R_s = solar radiation in langleys

The R_s in the above relation was estimated as per the procedure out-lined by Doorenbos and Pruitt (1977).

Baier method

$$PET = 0.0034 [(T_{max} x0.928)+0.933(T_{max} - T_{min}) + 0.0486 R_A - 87.03] \quad ...(Eq.5)$$

where,

T_{max}, T_{min} are maximum and minimum temperatures in°C and R_A was deduced as explained earlier.

After computing PET by different methods, the data were separated into three seasons namely *kharif* (June- Sept.), *rabi* (Oct.-Jan.) and summer (Feb.-May). The accuracy of each method in comparison with modified Penman method was analyzed statistically by using root mean square (RMSE), mean bias (MBE) and mean percentage (MPE) error values as

$$RMSE = [\Sigma (PET_e - PET_p)^2/n]^{0.5}$$

$$MBE = [\Sigma (PET_e - PET_p)]/n$$

$$MPE = \{ \Sigma [(PET_p - PET_e)/PET_p]100\}/n$$

where, n = number of observations

PET_p = PET as estimated by modified Penman method

PET_e = PET as estimated by the empirical relation in question.

While determining MPE value, the sign of the errors were neglected and the percentage errors were added to calculate the mean.

RESULTS AND DISCUSSION

The PET values as estimated by different methods are compared with modified Penman method, which in the present study is taken as a reference, by detemining the mean deviation from the Penman method (Fig.1). The results indicate that all the methods differed considerably from the Penman method. Thornthwaite and Turc methods have over estimated the PET, whereas Baier method gave under-estimates. Off all the four relations, Hargreaves relation resulted in estimates closer to the Penman estimates.

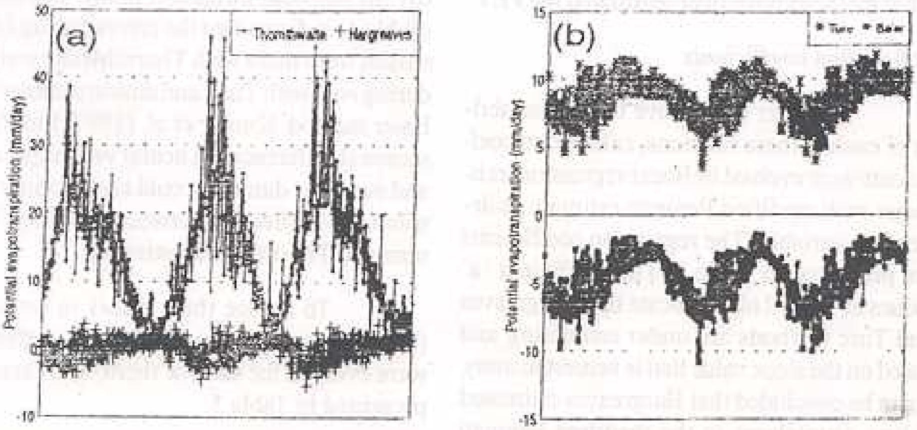

Fig. 1 : Deviations from modified Penman estimates

The Baier relation was employed for PET estimation for most of the Canadian sites where cooler temperatures are prevalent. The factor 87.03 in Eq.5 may not hold good for tropical weather conditions like those at Bapatla where the temperatures are relatively high.

Turc formula gave higher estimates but relatively lower than those from Thornthwaite's relation. Hargreaves grass related radiation method, though derived from cool season Alta fescue grass lysimetric data from Davis, California resulted in PET estimates close to modified Penman method. Thus this relation can be expected to give better estimates of PET for climatically analogous stations. The results statistically analyzed with the help of RMSE, MBE, MPE values, as a function of their deviation from Penman method, are presented in Table 1.

It could be seen from the MPE values that Hargreaves method resulted in about 21 per cent error followed by Baier, Turc and Thornthwaite method in that order. The MBE values indicated that except Baier method all other methods have over-estimated the PET.

Calibration coefficients

In order to improve the predictability of each of these relations, calibration coefficients were evolved by linear regression technique with modified Penman estimate as dependent variable. The regression coefficients are presented in Table 2. The coefficient 'a' values in Table 2 also indicate that Hargreaves and Turc methods are under estimating and based on the slope value that is nearest to unity, it can be concluded that Hargreaves estimated values were closer to the modified Penman estimates. The efficiency of these calibration coefficients in reducing the errors for each relation was determined by multiplying the PET as estimated by that relation with coefficient 'b' and then adjusting the product by the intercept i.e., 'a' value. The resultant PET estimates were again subjected to statistical analysis (Table 3).

The data in Table 3 indicates that the errors were narrowed down in each relation with the use of calibration coefficients. The magnitude of the reduction in errors was the highest with Thornthwaite method followed by Turc and Baier and the least with Hargreaves method.

Seasonality factor

The march of different relations as depicted in Fig.1 indicates that there could be some noise due to season. Kumar *et al.*(1987) indicated that Thornthwaite method tends to give higher estimates than Penman method during the monsoon season and Penman method gives higher estimates during winter season. These observations have prompted us to separate the data into different seasons and subjecting them to statistical analysis to quantify the seasonal influence, if any. The results (Table 4) indicate that the errors during *kharif* season were more with Thornthwaite method, during *rabi* with Turc, and during summer with Baier method. Kumar *et al.* (1987) found that seasonal differences in actual vapour pressure and sunshine duration could significantly contribute to diffrences between modified Penman and Thornthwaite estimates.

To reduce these errors in estimates (Table 3), season-wise calibration coefficients were evolved for each of them, and these are presented in Table 5.

The PET values were estimated using the season specific coefficients, and the

Table 1: Performance of empirical relations in comparison to modified Penman method (pooled data)

Parameter	Thornthwaite	Hargreaves	Turc	Baier
RMSE	19.53	1.42	8.88	4.78
MBE	+14.85	+0.34	+8.77	-4.44
MPE	342.23	21.04	258.23	104.55

Table 2 : Calibration coefficients for the four empirical relations

Relation	a	b	R^2	r
Thornthwaite	2.6908	0.0832	0.42	0.65
Baier	13.3630	56.6715	0.25	0.57
Hargreaves	-0.8408	1.1085	0.39	0.63
Turc	-26.5529	2.3624	0.59	0.77

Table 3: Performance of empirical relations with calibration coefficients

Parameter	Thornthwaite	Hargreaves	Turc	Baier
RMSE	41.182	46.199	37.163	52.772
MBE	-0.055	+0.014	+0.036	-0.013
MPE	11.642	10.796	7.583	13.914

Table 4: Influence of season on the performance of different methods

Season	Parameter	Thornthwaite	Hargreaves	Turc	Baier
Kharif	RMSE	20.404	1.378	10.589	4.952
	MBE	+18.988	+0.196	+10.535	-4.66
	MPE	451.395	16.081	285.898	104.298
Rabi	RMSE	6.304	1.347	11.391	3.017
	MBE	+5.774	+1.190	+11.376	-2.949
	MPE	219.272	47.648	434.450	106.632
Summer	RMSE	17.94	1.506	10.69	4.968
	MBE	+15.029	+0.201	+10.63	-4.59
	MPE	338.119	19.516	302.632	448.239

Table 5 : Season - wise calibration coefficients

Season	Relation	a	b	R^2	r
Kharif	Thornthwaite	1.137	0.143	0.53	0.73
	Hargreaves	-0.303	1.023	0.35	0.59
	Turc	-22.421	1.792	0.66	0.81
	Baier	14.048	59.541	0.32	0.56
Rabi	Thornthwaite	2.039	0.086	0.13	0.36
	Hargreaves	0.713	0.521	0.24	0.49
	Turc	-10.069	0.907	0.61	0.78
	Baier	5.232	14.754	0.07	0.26
Summer	Thornthwaite	1.829	0.134	0.64	0.80
	Hargreaves	-0.986	1.164	0.39	0.62
	Turc	-22.987	1.819	0.83	0.91
	Baier	14.073	60.387	0.26	0.51

Table 6 : Performance of each relation with season-wise calibration coefficients

Season	Parameter	Thornthwaite	Hargreaves	Turc	Baier
Kharif	RMSE	1.35	1.86	0.98	1.16
	MBE	-0.001	-0.0001	+0.00001	+0.00007
	MPE	8.597	10.87	4.902	11.65
Rabi	RMSE	0.371	0.570	0.406	0.630
	MBE	-0.00003	0.00006	0.000008	0.00004
	MPE	5.198	1.480	0.786	1.631
Summer	RMSE	1.139	1.480	0.786	1.631
	MBE	0.0002	-0.00012	0.0003	-0.00003
	MPE	8.937	12.08	2.148	15.541

resultant estimates were again subjected to statistical analysis, and the results are presented in Table 6. It is noticed by comparing results of Table 3 with those reported in Table 6, that season specific calibration coefficients reduced considerably the errors irrespective of the method used.

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